Quarterly Progress Report

For: METHANE de-NOX® for Utility PC Boilers

Covering Period: July 1, 2000 to September 30, 2000

Date of Report: October 30, 2000

Recipient: Institute of Gas Technology (IGT)
1700 Mount Prospect Road
Des Plaines, IL 60018-1804

Award Number: DE-FC26-00NT40752

Subcontractors: Babcock Borsig Power (BBP) [formerly DB Riley, Inc. (DBR)]
Gas Research Institute (GRI)
All-Russian Thermal Engineering Institute (VTI)

Partners: IGT Sustaining Membership Program (SMP) will provide cash co-funding in the amount of $150,000. GRI will provide cash co-funding in the amount of $700,000. BBP will provide in-kind co-funding in the amount of $97,000.

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Project Objective: The overall project objective is the development and validation of an innovative combustion system, based on a novel coal preheating concept prior to combustion, that can reduce NO_x emissions to 0.15 lb/million Btu or less on utility pulverized coal (PC) boilers. This NO_x reduction should be achieved without loss of boiler efficiency or operating stability, and at more than 25% lower levelized cost than state-of-the-art SCR technology. A further objective is to make this technology ready for full-scale commercial deployment by 2002-2003 in order to meet an anticipated market demand for NO_x reduction technologies resulting from the EPA's NO_x SIP call.

Background: Achieving NO_x emissions levels of 0.15 lb/million Btu requires NO_x reduction on the order of 90 % from uncontrolled levels. Conventional measures for NO_x reduction in PC combustion processes primarily rely on combustion modifications and post combustion controls. In general, combustion modification technologies try to reduce the formation of NO_x precursors while destroying already-formed NO_x. A variety of NO_x reduction technologies are in use today, including Low-NO_x Burners (LNB's), flue gas recirculation (FGR), and gas or other fuel reburning. Selective Non-Catalytic Reduction (SNCR) and Selective Catalytic Reduction (SCR) are post combustion techniques. NO_x reduction efficiencies from these technologies vary from 30 to 60%, with up to 90% for SCR.

A novel pulverized coal-preheating approach for NO_x reduction has been developed by the All Russian Thermal Engineering Institute (VTI), in Russia, for use on PC utility boilers. The technology consists of a burner modification that preheats pulverized coal to elevated temperatures (up to 1500°F) prior to coal combustion. This releases coal volatiles, including fuel-bound nitrogen compounds, into a reducing environment, which converts the coal-derived nitrogen compounds to molecular N_2. The quantity of natural gas fuel required for PC preheating is in the range of 3 to 5% of the total burner heat input. Basic combustion research and development of the preheat PC burner was conducted by VTI in the early 1980's. Following these promising laboratory results, commercial-scale coal preheat burners of 30 and 60 MW_t capacity were developed and demonstrated in field tests conducted in several Russian power stations:

The advanced pulverized coal (PC) preheat combustion system being developed in this project combines the VTI preheat burner together with elements of IGT's successful METHANE de-NOX technology for NO_x reduction. METHANE de-NOX has been commercially demonstrated on coal, MSW and biomass-fired stoker boilers in the U.S. and Japan. Overall, the new PC preheat system combines several NO_x reduction strategies into an integrated, low-NO_x, PC combustion system, including a novel PC burner design using natural gas-fired coal preheating, and internal and external combustion staging in the primary and secondary combustion zones. This integrated system can achieve very low NO_x levels – down to 0.15 lb/million Btu – without the complications, limitations and expense of SCR or SNCR technology.

Status:

Task 1.1 *Pilot-Scale Design*

Work during the quarter included completion of comprehensive laboratory analyses of the four U.S. coals and three Russian coals selected for evaluation last quarter. Using the NO_x reduction correlations developed previously by VTI and transmitted to IGT during the last quarter as part of the PC Preheat technology transfer agreement, IGT then developed performance projections for the PC Preheat technology with the selected U.S. utility coals. The first issue of the pilot-scale preheat burner specifications and design documentation was received from VTI and an initial design review was completed by IGT. Review comments have been forwarded to VTI and design revisions are currently underway. Preliminary modeling of the natural gas-fired preheat burner design was started based on the favorable results of IGT's in-house bench scale testing of a prototype natural gas burner for use in the pilot-scale preheat burner testing at BBP.

<u>Laboratory Analysis of Selected Coals</u>

Six U.S. coals were selected for initial screening, and four were selected by the project team for comprehensive analysis. In addition, three Russian coals that were studied extensively by VTI in the development of the coals preheating burner technology were also evaluated using the same laboratory methods. The analyses performed on these coals are summarized in Table 1:

Table 1. Analytical Methods

ANALYSIS	METHOD	DESCRIPTION
Proximate analysis	ASTM D3172	Measures moisture, ash, and volatile matter by weight
Ultimate analysis	ASTM D3176	Determines major elements by weight
Calorific value	ASTM	Measures heating value
Sulfur by type	ASTM D2492	Determines forms of sulfur as pyritic, organic, sulfate, and elemental sulfur
Free swelling index	ASTM D720	Measures caking/swelling tendency
Particle density	Micrometrics 9310 mercury porosimeter	Measures density of coal particle; also measures pore size distribution excluding micropores
Ash fusion temperature (oxidizing and reducing)	ASTM D1857	Measures development of ash fluidity at combustion temperatures
Ash composition (major and minor oxides)	ASTM D2795, ASTM D3682	Determines oxide composition of ash
Pyrolysis-GC	CDS Analytical Pyroprobe 1000	Measures products of rapid pyrolysis by on-stream analysis of volatiles up to C_{40}; pyroprobe is interfaced with GC which can use FID, TCD, or NPD detector

The four U.S. coals for extended study were selected to cover a wide range of physical and chemical properties and to present a suitable representation of coals widely used in U.S. PC boilers for power generation. Coals were selected specifically with the participation of two major U.S. electric utilities that have expressed interest in field demonstration of this technology. One Western coal and three Eastern coals were selected, and their major properties are shown in Table 2, followed by properties of the three Russian coals for comparison.

Evaluation of pyrolysis behavior was performed using the pyrolysis-gas chromatograph method shown at the bottom of Table 1. In the CDS Pyroprobe, a 1-mg coal sample is preheated to 550°F under helium to remove moisture and adsorbed gases, then heated rapidly to the desired pyrolysis temperature by capacitive discharge through a Pt coil surrounding the sample. The heating rate and final temperature are programmable. For these analyses, the heating rate (10,000 °F/s) was selected to represent the preheating section of the burner, and final temperatures of 1200, 1400, and 1600°F were studied.

The method yields a “pyrogram” which shows the distribution of volatile components as measured by a flame ionization detector (FID). The chromatograms were integrated in six ranges: C_1-C_4, C_5-C_6, C_6-C_{12}, C_{12}-C_{18}, C_{18}-C_{24}, and C_{24}-C_{40}. The method is unable to measure hydrocarbons above C_{40}, but our experience with coal pyrolysis has shown that this fraction is typically less than about 2% of total volatiles.

These data show that there are very significant differences in devolatilization behavior between the four selected U.S. coals and the Russian coals. It is immediately apparent that the release of volatile hydrocarbons is a larger fraction of the coal organic matter for U.S. coals than for Russian coals, with the exception of the highest-volatile Russian coal 1251-02, which is comparable to the lowest-volatile U.S. coal 1261-02. These data will now be used to determine

Table 2. Analyzed Properties of Four U.S. and Three Russian Coals

COAL ORIGIN	US—Western	US—Central Appalachian	US—South Appalachian	US—Illinois Basin	Russia—lean coal	Russia—brown coal	Russia—bituminous
COAL ID #	1183-01	1261-01	1261-02	1261-03	1251-01	1251-02	1251-03
ASTM RANK	SubbitA	HVbitB	MVbit	HVbitC	Semianthr	SubbitB	HVbitC
PROXIMATE, % as rec'd							
Moisture	10.68	2.10	1.40	10.41	2.75	10.46	1.63
Ash	6.09	9.58	16.29	8.80	21.81	5.80	43.80
VM	37.54	32.13	26.82	34.52	11.58	41.64	18.21
Fixed carbon	45.69	56.19	55.49	46.27	63.86	42.10	36.36
ULTIMATE, % dry							
C	70.77	75.70	70.78	71.15	68.82	64.75	43.50
H	5.28	5.05	4.57	5.14	2.69	4.47	2.93
S	0.80	0.73	1.64	4.64	0.31	0.29	0.59
N	1.24	1.38	1.29	1.42	1.40	0.76	0.76
O (by diff)	15.09	7.35	5.20	7.83	4.35	23.25	7.69
Ash	6.82	9.79	16.52	9.82	22.43	6.48	44.53
HHV, Btu/lb dry	12,610	13,530	12,590	12,980	11,360	10,730	7,330
HHV, Btu/lb wet	11,263	13,246	12,414	11,629	11,048	9,608	7,211
Sulfur by type, % dry							
Sulfide	NA	< 0.01	< 0.01	0.02	< 0.01	< 0.01	< 0.01
Sulfate	NA	0.03	0.23	0.21	0.03	0.06	0.11
Pyritic	NA	0.15	0.56	1.92	0.14	0.07	0.29
Organic	NA	0.55	0.85	2.49	0.14	0.16	0.19
Total	0.80	0.73	1.64	4.64	0.31	0.29	0.59
FSI	0.0	4.5	7.0	4.5	0.0	0.0	0.0
Particle density, lb/ft^3	78.7	81.9	84.8	74.9	NA	NA	NA
Mean C_p, dry (1200°F)*	0.590	0.527	0.489	0.566	0.384	0.621	0.429
Ash fusion temp, °F							
Reducing							
Initial	2085	2360	2670	2165	2375	2280	2700
Softening (H=W)	2100	2410	2695	2180	2440	2345	2700
Hemispherical	2120	2460	2700	2210	2510	2360	2700
Fluidity	2140	2515	2700	2250	2590	2380	2700
Oxidizing							
Initial	2200	2515	2700	2405	2585	2370	2700
Softening (H=W)	2215	2540	2700	2435	2615	2395	2700
Hemispherical	2240	2575	2700	2470	2640	2415	2700
Fluidity	2265	2605	2700	2510	2675	2450	2700
Ash composition, %							
Na_2O	3.07	0.49	0.27	0.50	0.53	0.44	0.22
MgO	5.06	1.64	0.68	0.73	0.80	3.66	0.22
Al_2O_3	13.65	24.00	23.44	17.65	19.09	8.24	29.11
SiO_2	29.95	52.41	61.82	40.64	60.96	19.96	61.82
P_2O_5	< 0.20	0.11	< 0.11	< 0.11	0.32	< 0.18	0.34
SO_3	12.17	4.44	0.46	2.50	1.01	7.54	0.05
K_2O	1.25	3.61	2.22	2.11	2.57	0.59	0.86
CaO	19.17	3.44	0.49	2.08	1.75	33.02	0.31
TiO_2	0.65	1.20	1.82	0.82	0.87	0.42	1.25
ZnO	0.61	0.00	0.00	0.00	0.00	0.00	0.00
BaO	0.31	0.00	0.00	0.00	0.00	0.00	0.00
Fe_2O_3	9.27	6.66	7.21	27.60	9.50	16.59	4.85
Unidentified	4.85	1.99	1.60	5.37	2.61	9.54	0.99

* Includes heat of devolatilization

the natural gas-fired preheat burner heat release requirements for the pilot-scale burner assembly, and to characterize chemical and physical properties of the vapor phase pyrolysis products so that the required velocity and residence time is maintained in the preheat section ahead of the PC burner.

Preheat Burner Performance Projection with U.S. Coals

The preheat burner development to date includes extensive laboratory and field demonstration work that was performed by VTI using 20 Russian coals ranging from brown coal to anthracite. Extensive experimental work with three of these coals led to a correlation of NO_x reduction with two process variables: preheat temperature and coal volatile matter content. The VTI correlation is based on the equation:

$$NO_t/NO_0 = 1 - 0.00535\,(t + 6.7V_{maf} - 500)^{0.8}$$

where NO_t is flue gas NO_x from combustion of coal preheated to temperature t, NO_0 is flue gas NO_x from combustion of the same coal without preheating, t is the preheat temperature in °C, and V_{maf} is weight percent volatile matter of coal on moisture- and ash-free basis. In this context, the four selected U.S. coals were evaluated for projected performance over the temperature range of 800-1500°F. The results are shown in Table 3 and in Figure 1.

Table 3. Predicted NO_x Reduction for U.S. and Russian Coals

COAL ORIGIN	US—Western	US—Central Appalachian	US—Southern Appalachian	US—Illinois Basin	Russia—lean coal	Russia—brown coal	Russia—bituminous
COAL ID #.	1183-01	1261-01	1261-02	1261-03	1251-01	1251-02	1251-03
ASTM Rank	SubbitA	HVbitB	MVbit	HVbitC	Semianthr	SubbitB	HVbitC
VM, %maf	45.10	36.38	32.58	42.73	15.35	49.73	33.37
N content, lb/MMBtu	0.98	1.02	1.03	1.09	1.23	0.71	1.04
Preheat Temp, ° F	---------------------------- Predicted NO_t/NO_0 ratio ----------------------------						
800	0.587	0.674	0.713	0.610	0.920	0.543	0.705
900	0.508	0.591	0.628	0.531	0.813	0.466	0.621
1000	0.433	0.513	0.548	0.454	0.720	0.392	0.541
1100	0.360	0.437	0.471	0.381	0.635	0.320	0.464
1200	0.289	0.364	0.397	0.309	0.554	0.250	0.390
1300	0.220	0.293	0.325	0.240	0.477	0.182	0.318
1400	0.152	0.224	0.255	0.172	0.403	0.115	0.248
1500	0.086	0.156	0.187	0.105	0.331	0.049	0.180

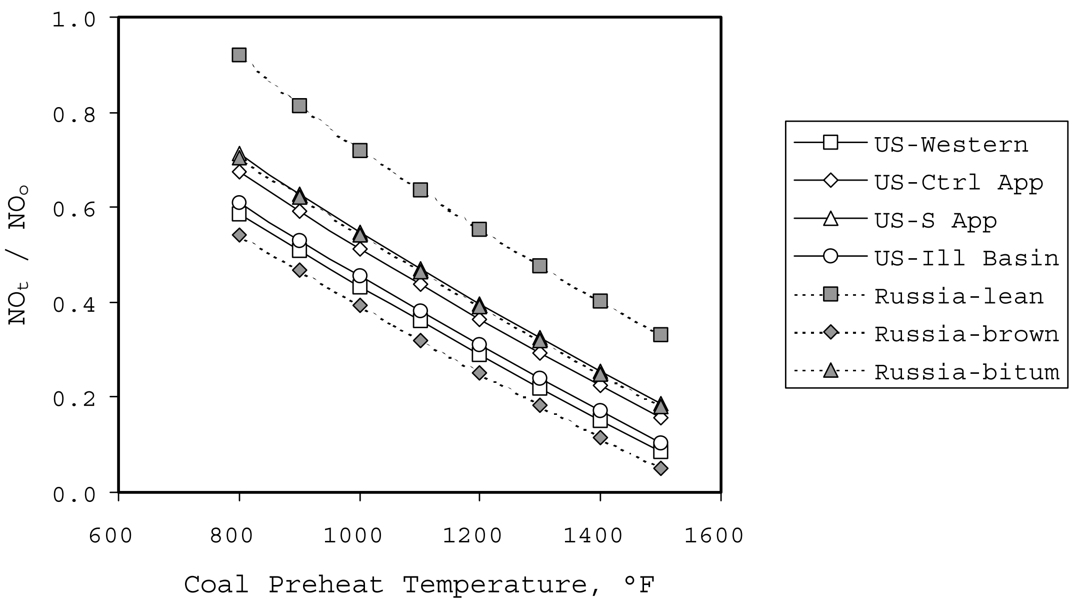

Figure 1. Plot of NOx Reduction versus Preheat Temperature for U.S. and Russian Coals

Most U.S. coals that are used in power generation have fairly high volatile matter content, which is required by the power plant specifications. The selected coals are typical, and the NO_x reduction is expected to be similar to that of Russian coals with similar volatile content. For example, at 1400°F preheat temperature, the NO_t/NO_0 ratio for U.S. Southern Appalachian bituminous coal (1261-02) is 0.255 (74.5% NO_x reduction) compared to 0.248 (75.2% NO_x reduction) for the Russian bituminous coal (1251-03) with similar volatile matter. Except for the Russian brown coal (1251-02), the nitrogen contents of the coals at equivalent heating value are also similar, so the NO_x reduction on a lb/MMBtu basis will be similar. These predicted results will be confirmed in pilot and commercial prototype testing later in this project.

An important consideration for burner design is the agglomerating or caking properties of some U.S. coals. U.S. coals 1261-01, 02 and 03 are bituminous coals with mild to strong agglomerating tendency. This property is not normally important for PC combustion, but it will be important in the preheating burner, which functions similarly to an entrained coal pyrolysis reactor. None of the Russian coals had significant caking tendency. IGT will use its strong background in gasification and pyrolysis of agglomerating coals, going all the way back to the early 1970's, to incorporate design features into the burner that will facilitate operation with these coals. Key design issues include:

- Ejection of coal particles from the PC delivery tube prior to development of mesophase (sticky phase) at approximately 350-400°C
- Rapid dispersion and mixing of the coal particles into the preheating medium (gas burner combustion products)
- Rate of heat transfer to the coal particles sufficient to destroy the agglomerating property prior to wall contact

The burner will be designed with these issues fully addressed, based on extensive published studies of pyrolysis of caking coals and direct IGT experience with coal pyrolysis. CFD modeling will be utilized to model the gas velocity profiles, temperature and pressure distributions, particle trajectories, heat transfer, and mass transfer properties in the burner under design operating conditions.

Based on these data, the design case (US—Illinois Basin Coal 1261-03, preheat temperature 1400°F) is projected to result in a NO_x reduction of 82.8%, compared to uncontrolled PC combustion. Combustion air staging (LNB design) and application of METHANE de-NOX® reburning is projected to reduce NO_x typically by an additional 50%, resulting in an overall NO_x reduction of 91.4%. Based on current PC boiler NO_x emissions of 0.8-1.6 lb/MMBtu, the projected flue gas emissions will be below 0.14 lb/MMBtu.

VTI Pilot-Scale burner Design and Review

The first issue of the pilot-scale PC preheat burner specifications and design documentation was received from VTI and an initial design review was completed by IGT. A summary of the pilot burner design documentation received is presented in Attachment 1. The primary design issues identified in IGT's review were as follows:

- U.S. PC boilers are typically fed directly from air swept pulverizers with coal/air mass ratios in the feed stream of about 0.5 – 1.0 lb coal / lb air. To maintain a low stoichiometric air ratio during preheating, a cyclone separator will be used to remove most of the transport air prior to entering the PC preheater.
- The separated air from the cyclone will be routed initially to one of the coal burner air channels rather than overfire air ports on the furnace. Later testing will consider both air and fuel staging, after the NOx reduction performance of the preheat PC burner alone is characterized.
- Preheat residence time will be varied during testing by adding or removing sectional preheater piping between the natural gas-fired preheater and the PC burner. The preheater pipe sections will be air cooled to simulate the conditions in a full-scale burner. Differential thermal expansion of the inner and outer pipes will be accommodated with sealed bellows, as will the overall thermal expansion of the preheater assembly.

IGT's review comments have been forwarded to VTI and design revisions are currently underway. A process flow diagram and preliminary assembly drawing are in preparation by IGT for review by BBP.

Task 1.2 *CFD Modeling*

IGT conducted substoichiometric firing tests of a pilot-scale prototype for the natural gas-fired preheater burner. The data collected during these tests was used to develop a preliminary spreadsheet model from which the CFD model will be developed.

Task 1.3 *Pilot-Scale Equipment Fabrication and Installation* – No Activity

Task 1.4 *Pilot-Scale Testing* – No Activity

Task 1.5 *Pilot-Scale Data Evaluation* – No Activity

Task 1.6 *Task 1 Management and Reporting*

Work during the quarter included Project review and planning meetings with VTI and BBP, finalizing the project cofunding arrangements and execution of necessary subcontracts.

- Three VTI scientists involved in the original development of the coal preheat technology visited IGT offices in July to continue the technology transfer process.
- IGT and the VTI project personnel visited BBP's burner test facility to review/complete the 3 MMBtu/h pilot-scale preheat burner design and review test facility requirements for the pilot-scale burner.
- IGT proposal No. 18652-86 for GRI cofunding received final approval and a contract in the amount of $700,000 is now in place (IGT Project No. 32049).
- Subcontract negotiations were concluded with BBP for burner fabrication, installation and testing activities at their Worchester, MA research facility. The subcontract has been forwarded to BBP for signature.

Plans for Next Quarter:

- The 3 MMBtu/h pilot-scale preheat burner design will be completed and fabrication/installation at the BBP test facility will be started.
- The pilot-scale test plan and matrix will be prepared
- Continue CFD modeling of the preheat burner system and boiler for the pilot- and commercial-scale cases.

Milestone Status Table: The planned completion dates for all project tasks and major milestones are shown in the following table. As of this date, IGT expects the overall project to be completed on schedule in August 2002.

ID No.	Task / Milestone Description	Planned Completion	Actual Completion	Comments
♦	Kickoff Meeting	5/2/2000	5/2/2000	Complete
1.0	Technology Development			
1.1	Pilot-Scale Design	8/31/2000		75% Complete
1.2	CFD Modeling	6/30/2001		Started
1.3	Pilot-Scale Equipment Fabrication and Installation	11/30/2000		
1.4	Pilot-Scale Testing	3/31/2001		
1.5	Pilot-Scale Data Evaluation	4/30/2001		
1.6	Task 1 Management and Reporting	4/30/2001		
♦	Task 1 Report	4/30/2001		
2.0	Technology Validation			
2.1	Commercial Prototype Engineering Design	7/31/2001		
2.2	Baseline Data Review	7/31/2001		
2.3	Commercial Prototype Construction	10/31/2001		
2.4	Commercial Prototype Testing	2/15/2002		
2.5	Data Processing and Evaluation	3/31/2002		
2.6	Commercialization Plan Development	6/15/2002		
2.7	Design and Fabrication of Commercial Burner System	7/31/2002		
2.8	Task 2 Management and Reporting	8/10/2002		
♦	Final Report	8/10/2002		

ATTACHMENT 1

	SUBJECT: PC PREHEAT BURNER DRAWING SUMMARY				Gas Technology Institute COMBUSTION TECHNOLOGY GROUP 1700 S. Mt. Prospect Rd Des Plaines, Illinois 60018 **Date:** October 27, 2000 **Revision:** 0	
Drawing No.	**Drawing Title**	**Date**	**Rev.**	**Item #**	**Paper Size** (mm x mm)	**ACAD File Name**
VTI						
1-00.10 (SHEET 1 OF 2)	Additional Devices for the Test Facility - 3 mmBtu/h (Sheet 2 of 2 Plan views)	09.00	0	-	-	Komponovka-1.jpg (Note: not an ACAD file)
1-00.10 (SHEET 2 OF 2)	Additional Devices for the Test Facility - 3 mmBtu/h (Sheet 1 of 2 Elevations views)	09.00	0	-	-	Komponovka-1.jpg (Note: not an ACAD file)
1-00.11	Location of the Test Burner	09.00	0	-	1108 x 720	Burner 1.dwg
1-00.20 (SHEET 1 OF 2)	Additional Devices (Sheet 2 of 2 Plan elevations)	09.00	0	-	-	Komponovka-2.jpg (Note: not an ACAD file)
1-00.20 (SHEET 1 OF 2)	Additional Devices for PC Coal Supply Sys (Sheet 2 of 2 Elevations views)	09.00	0	-	-	Komponovka-2.jpg (Note: not an ACAD file)
1-01	Dependence of the necessary temperature of pc preheating on desired NOx reduction	07.00	0		215 x 279	Fig 1-01.doc (NOT an ACAD file)
1-01.00	Mixer	09.00	0	1	267 x 400	Mixer1.dwg
1-02.00	Compensator	09.00	0	2	267 x 400	Compensator.dwg
1-03.00	Partial Oxidation Combustor			3		by IGT
1-04.00	PC Preparation Facility	09.00	0		2870 x 4050	PC coal heater-faterr.dwg
1-04.10 (SHEET 1 OF 2)	1st PC Preparation Area (Sheet 1 of 2)	09.00	0	4	574 x 820	PC coal heater.dwg
1-04.10 (SHEET 2 OF 2)	1st PC Preparation Area (Sheet 2 of 2)	09.00	0	4	574 x 820	"
1-04.20	FGR Mixer	09.00	0	5	574 x 810	PC coal heater-2.dwg
1-04.30	2nd PC Preparation Area	09.00	0	6	574 x 810	PC coal heater-3.dwg
1-05.00	The Test Burner	09.00	0	7	1540 x 1108	Burner 2.dwg
1-05.10	Central Tube	09.00	0	7	1560 x 1108	Central tube.dwg
1-05.20	Pipe of PC Duct	09.00	0	7	1560 x 1108	Tube 1.dwg
1-05.21	Vane	09.00	0	7	180 277	Inner vane.dwg
1-05.30	Duct and Pipe of Inner Secondary Air Duct	09.00	0	7	1560 x 1108	Tube and duct-inner.dwg
1-05.31	Vane	09.00	0	7	180 x 277	Outer vane.dwg
1-05.40	Duct and Pipe of Peripheral Secondary Air Duct	09.00	0	7	1560 x 1108	Tube and duct-outer.dwg
1-06.00	PC Coal Tube	09.00	0	8	3900 x 5740	PC coal tube.dwg
1-07.00	Ejection Mixer	09.00	0	8	554 x 360	Mixer.dwg
1-08.00	PC Coal Cyclone	09.00	0	9	3900 x 5740	PC coal cyclone.dwg
1-09.00	Distributor	09.00	0	10	390 x 574	Divisor.dwg